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Economic analysis of investment in the rooftop photovoltaic systems: A long-term research in the two main markets

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ABSTRACT

Nowadays, due to incentive policies, the PhotoVoltaic (PV) installations become an economically attractive investment. The different policies aim to reduce the PV installation costs, consequently to the deployment of the market. In recent years, a progressive price decrease of components for PV installations has occurred, according their learning curve: every doubling of the volume implies approximately a cost reduction of −20%. In order to reduce the burden of the incentive rate on the national budget, maintaining the economic margin of the investment attractive for investors, a progressive tariff decline has also taken place. This paper provides a technical-economic analysis of investments in PV systems installed on the rooftop, considering incentive policies, and applies it to some significant case studies in the Countries, in which PV market is the most prosperous (Germany and Italy). The analysis puts into evidence the past and current economic margins of the PV investments since 2006 to 2012. Four case studies from 3 kWp to 1 MWp are examined in detail. The profitability indexes in terms of net present value and internal rate of return, evaluated throughout incentive duration of 20 years, become very interesting above all in Italy (higher than 100% of the installation cost and higher than 10%, respectively) since 2009, when an abrupt decrement in installation cost occurred. In Italy the best profit margins occur for large-size PV plants and are poorly counterbalanced by the decline of the feed-in tariff up to 2012, when a new framework has given a knock to the investments, whereas in Germany the best margins happen for medium-size PV plants and are well adjusted by the feed-in tariff. However, it is predictable that a cut in German feed-in tariff will take place, because the profit margins have been higher in last year than in the previous years.

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1. Introduction

In the past the installation cost of PhotoVoltaic (PV) systems was so high that no economic convenience appeared, with respect to the bill paid to the utilities for the grid electricity. That was the

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reason, for which the stand alone PV systems were the unique applications of this technology in zones where the network was not available as in mountains, islands or rural sites. The increasing costs of fossil fuels, due to the impressive usage around the world, and the consequent concerns on climate change (greenhouse gases, global warming) have pushed the national Governments towards a major employment of Renewable Energy Sources (RES), according to several protocols as e.g. the Kyoto one. Especially in Europe, in the last years, a policy for RES deployment, based on incentive in terms of feed-in tariffs, has been implemented. These tariffs have produced, for the owners of PV systems, such revenues that also the grid connected PV plants have become viable from the economic point of view. Obviously, the money for the incentive is a burden for the community, but, if the mechanism is well done, it can generate many advantages like reduction of installation cost due to economies of scale, clean electricity production, job creation, technological innovation and safe investments. In fact, the main target should be to create a self-sustaining market based on two factors: firstly, the economies of scale [18], i.e., the decrements in cost per unit, that PV companies achieve (about −20%), as the size of the facilities and the usage levels of other inputs increase; secondly, the cost of electricity from fossil fuels which is continuously increasing. After the start-up period, the feed-in tariff should be progressively reduced, in such a way as to reduce the burden on the electricity bill and to hold an attractive performance of the PV investments. Nowadays, Germany and Italy are the main markets in the world for PV installations: in Germany the feed-in tariff is in operation since 2000 with about 30 GW_p of installed power and in Italy since 2005 with about 17 GW_p, after many adjustments. The goal of this paper is to provide a long-term research on the investments in regards to PV plants of active users charged by the retail electricity price with different size and location, roof mounted, in Germany and Italy, according to the variable conditions of the incentives (2006–2012). Such a study permits to determine the particular economic revenues during the time evolution among the various types of PV systems, emphasizing the efficiency of the incentive policies in the two major markets. At this aim, the installation costs of the PV plants, according to size, location and begin of life, have been defined by suitable assumptions; then, the performance indicators in terms of Net Present Value (*NPV*) and Internal Rate of Return (*IRR*) have been computed. This work was performed within the “Europe-China Energy Centre” (EC2) project with the support of the Italian Ministry for the Environment, Land and Sea. The Centre is managed by a consortium of nine partners – six European and three Chinese – led by Politecnico di Torino (Italy).

2. The worldwide PV market

Globally, the volume of new PV capacities world-wide rose from 16.6–20.2 GW_p in 2010 to 24.1–27.6 GW_p in 2011 considering a remarkable difference between the installed power and the grid-connected power (typical delay of some months in Italy). The number of markets reaching more than 1 GW_p of additional capacity during 2011 rose from 3 to 6 [5]. The European share in the global PV arena still remains predominant with more than 75% of all new capacity in 2011. The two biggest markets, Italy and Germany, account for nearly 60% of global market growth during 2010 [20]. The growth rate of PV during 2011 reached almost 70%, with growing contributions from Southern European countries, over 60 GW_p of PV systems were installed at the end of 2011. In Italy and France, specific regulations created strong installation growth in 2010; however, the grid connection was to be counted only in 2011. This effect has included between 3 and 5 GW_p of installations made in 2010 with grid connection taking place in 2011.

Table 1 shows the top markets world-wide, both in terms of grid-connected capacity during 2011 and 2010 and cumulative installed capacity at the end of 2011. It is interesting to note that China, at first place of PV module manufacturers in the world, is becoming an important market in the PV installation.

The growth of the PV market is based on the increasing oil prices and consequent air pollution, on the requirement of environmentally friendly energy generation, and is sustained by the support of the environmentally-conscious public incentives, direct subsidies and Research and Development (R&D) support. Without such support, the industry could not grow to levels that would enable the reduction of the price of electricity generated from photovoltaics to the levels of conventional energy generation [21]. Due to the increasing market volume, performance and reliability of PV systems have become key issues for minimizing business risks and increasing market actors' trust. A more accurate yield prognosis and information on operational availability of PV systems are crucial for investment decisions and market growth. In this context, performance and yield data, reliability statistics and empirical values concerning maintenance are by far more relevant today than in the past.

As previously mentioned, Europe remains the geographic area leader for PV installations. During 2010 Germany represented the most important country in the PV market with around 7.4 GW_p of installed new PV plants, while in 2011 Italy with around 9 GW_p of grid-connected new PV plants had the primacy. Spain, major player in 2008, has installed in the last years only around 400 MW_p per year. The reason is in the incentive policy change, with the introduction of a too low threshold for installations and significant cuts in tariffs. The main novelties of 2010 are in France and Czech Republic. As per France, the installed power during 2011 was around 1.5 GW_p, a very big increase compared to the previous year. Regarding Czech Republic, where the PV market is in the large part constituted by small and medium-sized plants (4.2 MW_p is the size of the largest PV plant built in 2010), the power installed in 2010 was 1360 MW_p, which has permitted to reach USA in the cumulative installed power, however the installation in 2011 has

Table 1
The installed and grid-connected capacity in 2010 and 2011.*Source*: IEA.

Country	2010 grid-connected capacity (MW)	2010 installed capacity (MW)	2011 grid-connected capacity (MW)	2011 installed capacity (MW)	2011 cumulative installed capacity (MW)
Italy	2321	5900	9000	5500	12500
Germany	7406	7406	7500	7500	24,700
China	520	520	2000	2000	2900
USA	887	887	1600	1600	4200
France	716	716	1500	1500	2500
Japan	986.8	986.8	1100	1100	4700
Spain	389	389	400	400	4200
Total in the world	16,629	20,208	27,650	24,150	67,350

gone down below 1000 MW_p. In addition, new European countries are entering in the PV market, for example Greece installed in 2010 around 150 MW_p and in 2011 around 350 MW_p, or Israel and Turkey had "strong" introduction of a new system of incentives in 2010. In Israel PV power of about 50 MW_p has been installed, but it is expected to reach in 2015 the target of 300 MW_p. In Turkey, despite the power installed in 2010 does not reach 10 MW_p, it is expected for 2015 a huge potential market [38].

3. Feed-in tariff policy and bureaucratic barriers

3.1. The Italian situation

GSE ("Gestore Servizi Energetici") is the Italian Energy Services Operator for the approval of incentives for the electricity production from renewable sources and receives the energy delivered to the grid by the so-called "Scambio sul Posto", i.e., on-site exchange [15]. The owners of solar PV systems can use the incentives and/or services described in the following list.

- The "Conto Energia" (CE, photovoltaic-electricity bill) is the incentive mechanism of production from solar photovoltaic energy. The incentive is paid according to the electricity production, since the grid-connection date of the PV plant for a period of twenty years. The rate is constant throughout the incentive period. The highest rate is approved for small domestic plants in building integratation; on the other hand, the lowest rates are recognized to the large plants not architecturally integrated.
  1. The first phase of CE program (issued in late 2005) was completed during 2009. In this context 5733 plants have been installed, corresponding to a total power around 164 MW_p. At this stage it was necessary to send the design documents to GSE for obtaining the assignment of the tariff before the installation.
  2. The second phase of CE program started in 2007, when the first phase was still in force, and was completed at the end of 2010. During this period, it resulted in setting into operation about 125,000 plants corresponding to a total power of 2736 MW_p. From this stage on, it was possible to install the PV plant and only after to send the final documents for the tariff assignment. Taking into account both the first and second phase, the installed PV power at the end of December 2010 was over 2.9 GW_p without the contribution of the so-called "Salva Alcoa" Decree. The feed-in tariffs were constant for 2007–2008 and only a −2% decay per year (period 2009–2010).
  3. In July 2010, a new edition of CE decree was established for the third phase At this stage the maximum power, that could have the feed-in tariff updated every quarter year, was limited to 3500 MW_p and a premium is given for PV plants with predictable power profiles.
  4. Furthermore, after a huge peak in PV installations, a fourth phase of CE decree, established in May 2011, was in force with an economic cap within 6 and 7 billion Euros for all the PV systems subject to incentive. Here, it is possible to distinguish between small and large grid-connected Photovoltaic (PV) Systems. *Small grid-connected PV* are: Building Integrated Photovoltaic System (BIPV) with peak power up to 1000 kW_p, other photovoltaic systems at ground level with peak power up to 200 kW_p operating under on-site exchange, and systems of whatever power in buildings and areas whose owner is a public administration (Municipalities, Provinces, Ministries, schools). These PV systems receive automatically the feed-in tariff according to the power levels. All other PV systems, not covered by this definition, are called *Large grid-connected PV systems* [16] and need the positive check of GSE after the registration in a suitable logbook.
  5. Finally, a fifth phase of CE is in force up to now, since August 2012, when the threshold of 6 billion Euros has been reached and the maximum cap has been fixed to 6.7 billion Euros. In this current mechanism the incentive is different because the PV energy is divided in two parts, one is the amount which is sold to the grid and the other one is the self-consumed that produces the maximum profit because it receives a premium tariff besides the saving in the utility bill.
- "Ritiro Dedicato" (Dedicated Delivery) is a GSE service in force, a simple way to place the electricity generated and fed into the grid on the electricity market through the GSE. PV systems have access to this service through the GSE for the delivery of all energy into the grid. The GSE recognizes to the producer of the PV plant a electricity price in €/kWh variable in the range 0.07–0.105.
- "Scambio sul Posto" (on-site exchange) is a mechanism operated by the GSE since January 2009 for PV plants powered by renewable energies with power up to 200 kW_p. It permits to give an economic value to the energy fed into the grid, according to an economic compensation principle with the energy value paid from the grid.

An additional amount in the feed-in tariff will be paid whenever the PV system is combined with energy saving techniques.

Differently from Germany, one of the main hindered problems for a more virtuous development of the Italian PV market in recent years has definitely been the excessive bureaucratization of the necessary authorization practices for the installation, the starting of the production and the promoting of a new facility.

The PV progress in Italy is impressive, particularly in 2010 when the so-called "Salva Alcoa" Decree has been implemented. In this Decree, the incentive rates, provided in 2010 by the 2nd "Conto Energia" feed-in tariff, are generously recognized in all PV systems, in which the installations of mounting structure and electrical components have concluded by December 2010 and the connection to the grid has performed by June 2011. As per the new installations, the year by year growth was +382% in 2008, +112% in 2009 and +192% in 2010. In this year about 138,900 new PV plants (2.1 GW_p of total PV power) started into operation, and other 55,000 PV plants (3.95 GW_p globally) have been completed. The total installed PV power, approximately shared in 210,000 plants in operation at the end of 2010, was 3276 MW_p, more than 64 times the value in 2007 [38].

As shown in Table 2, the residential systems (1–20 kW_p) decreased from 44.5% in 2007 to 19.4% in 2010. If in 2007 PV market was based on private customers who opted for the electrical system integration exploiting the space on their roof, in 2010 this phenomenon was in minority. The typical residential system customer is changed, both in terms of technologies knowledge and available implementation alternatives, and in terms of

Table 2
Number of installed PV plants and cumulative capacity according to the PV power range in 2011 in Italy.*Source*: GSE.

Cumulative values	Number of installed PV plants	Cumulative installed capacity [MW]
All PV plants	333,189	12,855
< 20 kW	292,492	1749
From 20 to 50 kW	11,847	468
> 50 kW	28,850	10,637

Table 3
Italian PV feed-in tariff for the first and second half of 2012. *Source*: [36].

Power Range [kW]	First half of 2012 [€/kWh]	Second half of 2012 [€/kWh]
$1 \le P \le 3$	0.274	0.252
$3 < P \le 20$	0.247	0.227
$20 < P \le 200$	0.233	0.214
$200 < P \le 1000$	0.224	0.202
$1000 < P \le 5000$	0.182	0.164
$P > 5000$	0.171	0.154

"contractual power" for installers, thanks to the "buying-groups" that install multiple PV systems with large size.

In Table 2 is reported the current number of installed PV plants and the installed capacity in Italy provided by the GSE in 2011. More than 90% of capacity is covered by high size plant, even if the most number of installed PV plants is within the 20 kWp power range. Moreover, the middle size power covers less than 3% of the total number and less than 4% of the total capacity. Table 3 provides the tariff rates valid up to August 2012 when the 5th CE has changed newly the amounts.

To obtain the incentive, the responsible person for PV system must submit relevant documents to the GSE, such as detailed drawings concerning electrical scheme with main devices (PV modules and their connections, grid-connected inverters, cables, protections and energy counters, etc.) and photos showing components and their locations in the plants. Moreover, as per the authorization, it must be submitted one of the following titles:

- the exclusive license ("Autorizzazione Unica" – AU) referred to the Article 12 of Legislative Decree n. 387/2003: the procedure lasts at least 6 months and requires a joint agreement from many public agencies;
- the Start Activity Document ("Denuncia di Inizio Attività" – DIA), according to the President of the Republic Decree n. 380 of 2001, if applicable, or the simplified habilitation declaration, according to the Legislative Decree n. 28/2011;
- the hard copy of free-construction document ("comunicazione di attività in edilizia libera"), referred to guidelines adopted pursuant to the Legislative Decree n. 387/2003 (the most simple and quickest procedure);
- the Start Activity Notice ("Comunicazione di Inizio Attività" – CIA) or the Start Activity Certificate ("Segnalazione Certificata di Inizio Attività" – SCIA), of the Ministerial Decree, n. 122/2010.

3.2. *The German situation*

The rapid increase of PV market in Germany began in 90's decade with the so-called "Thousand Roofs Programme", showing that the grid coupled feed-in from many small PV systems was technically possible [1]. The "Thousand Roofs Programme" sent a positive signal to the PV industry and provided an important impulse for the further development of the technology. It was aimed specifically at house owners and hence for the first time included private households in electricity generation; so these people became power producers. After this, the Renewable Energy Sources Act ("Erneuerbare-Energien-Gesetz" – EEG) in 2000 provided a reliable and long-term framework for PV and made solar electricity generation economically interesting. In terms of achieving expansion targets for renewable energies in the electricity sector, the EEG is actually the most effective funding instrument at the German government's disposal [33]. It determines the procedure of grid access for renewable energies and guarantees favorable feed-in tariffs.

The purpose of this Act is to facilitate a reliable development of energy supply, particularly for the sake of protecting the climate and the environment, to reduce the costs of energy supply to the national economy, also by incorporating external long-term effects, to preserve fossil fuels [44]. The Act aims to increase the share of renewable energy sources in electricity supply to at least 30% by 2020 and to continuously increase that share thereafter. The Act regulates: the priority connection to the grid for electricity supply of installations generating electricity from renewable energy sources within the Germany territory, including its exclusive economic zone; the priority purchase, transmission, distribution and payment for such electricity by the grid system operations, and the nationwide equalization scheme for the quantity of electricity purchased. For PV, the feed-in tariff depends on the system size and whether the system is ground mounted or attached to a building [22]. Since 2009, there is also a tariff for self-consumed power. The rates are guaranteed for an operation period of 20 years. Initially, a steady yearly reduction of the PV tariffs was foreseen. On the background of a constantly rising number of installations, a mechanism was introduced to adapt the EEG tariff to the market growth. Under this scheme, the reductions are increased or decreased if the market deviates from a predefined corridor. For 2009 this corridor was defined to be between 1000 MW_p and 1500 MW_p, which was significantly exceeded as the market reached 3800 MW_p. For 2010 to 2012, a new corridor between 2500 and 3500 MW_p was defined. Furthermore, for 2010 two additional reduction steps were agreed to adapt the tariff to the system price level. With around 7000 MW_p installed in 2010 the new corridor was surpassed again considerably. Beside the EEG support for the development of PV installations, the decrease of system prices continues which makes PV systems economically more and more attractive.

In addition to the EEG, PV receives support from other sources: local fiscal authorities provide tax credits for PV investments; the state owned bank (KfW-Bankengruppe) and other banks (e.g., UmweltBank and SwkBank) provides loans for individuals as well as for local authorities. Since at the beginning of 2009 the owners of new PV systems are legally obliged to register their systems at the German Federal Network Agency, which showed in 2011 an additional capacity of 7.4 GW_p and in total around 24.7 GW_p connected to the German grid.

As a consequence, Germany produced 12 TWh PV-electricity in 2010, which were roughly 2% of the national consumption. All renewable energies together have a share of 16.8% of the domestic energy supply. At the same time, the German National Renewable Energy Action Plan includes a target of a 38.6% share of renewable energies in the electricity sector for 2020. For PV, the scenario assumes a future development of annually 3500 MW_p from 2012 to 2020. This leads to an installed capacity of almost 52 GW_p in 2020 and a resulting electricity production of around 8% of the overall consumption.

In the debate over the second EEG revision in 2008, the rising remuneration payments drew intensive criticism as per their effectiveness. The growing demand for solar systems had been the reason that module prices did not drop proportionally with

Table 4
PV feed-in tariff of the EEG from 2010 in Germany.

Date of commissioning	< 30 kWp	Up to 100 kWp	Up to 1 MWp	> 1 MWp
01.01.2010–30.06.2010	39.14	37.23	35.23	29.37
01.07.2010–31.09.2010	34.05	32.39	30.65	25.55
01.10.2010–31.12.2010	33.03	31.42	29.73	24.79
01.01.2011–30.06.2011	28.74	27.33	25.86	21.56
01.07.2011–31.12.2011	24.43	23.23	21.98	18.33
2012 (−15%)	20.77	19.75	18.68	15.58

manufacturing costs. Solar companies thus made very high profits at this time. The new version of the Renewable Energy Sources Act, which came into force in 2009, therefore established a steeper digression of feed-in tariffs, increasing the rate of reduction from 5% annually to 8 or 10%.

System prices dropped further, by about 30% in 2009, even though the number of installed solar power systems grew considerably and more strongly than expected. Finally, the debate over support for solar power and changes in the feed-in tariffs illustrates the excellent development which Photovoltaics has undergone in recent years [1]. For typical home roof systems up to 30 kWp of capacity, feed-in tariffs of December 2011 is 24.43 ct €/kWh, as shown in Table 4. The costs of PV systems will drop still further in future. Solar PV power in Germany will reach the so-called grid parity from the active-user viewpoint, i.e. equal retail price as household power, as soon as in three years with a very high probability. That will be a watershed for investments in Photovoltaics, the self-produced power will be cheaper than what the power company can provide.

4. Economic analysis of a PV rooftop system

In recent years, a progressive price decrease of components for PV installations (modules, inverters) has occurred. In order to reduce the burden of the incentive rate on the national budget and maintain the investment attractive for investors, a progressive tariff decline is also occurred [4]. This section provides an economic analysis method of investments in PV systems installed on the roof, considering current incentive policies, and apply it to some significant case studies in the European Countries in which PV market is currently the most prosperous: Germany and Italy. This analysis highlights the current convenience margin of the PV investments.

The most important cost items for a PV plant are: the PV module costs (40–55% of total amount), the inverter/cable/protection costs (10%), the building-integration costs (10–15%), the installation costs (10–15%), the design/bureaucratic-document costs (5–10%). Usually, the support structure of PV modules influence only for a little, without a complete building integration. As per installation costs a continuous decline occurs. Concerning the PV modules, a reduction from 3200 €/kW$_p$ of 2009 to 1200 €/kW$_p$ of 2011 occurs for crystalline silicon; while regarding the thin film technology, the costs are reduced from 2200 €/kW$_p$ of 2009 to 1000 €/kW$_p$ of 2011 [19]. Nowadays, these figures are within 500–1000 €/kW$_p$ for the technologies available in market.

4.1. Investment assessment in PV systems by NPV and IRR

In order to determine the convenience of an investment, as for example the electricity production, with respect to other investments, a conventional method implies the assessment of the Net Present Value (*NPV*) and the Internal Rate of Return (*IRR*) during the PV plant life [37].

The parameters which influence the yearly *NPV* calculation [13,17] are:

- the installation cost C_I in €/y (IEA, 2006–2011 Trends in PV applications [23–28]);
- the rated power P_{PVr} in kW$_p$ of the PV system;
- the yearly Revenues, R_{PV} in €/y, are calculated as

$$R_{PV,k} = E_{AC} \cdot p_{PV} + E_{g\_inj} \cdot p_{inj} + E_{s\_cons} \cdot s_{bill} \tag{1}$$

  where: E_{AC} is the PV energy production in kWh; p_{PV} is the feed-in tariff unitary price in €/kWh; E_{g_inj} is the share of PV energy production delivered to the grid (different according to residential, commercial and industrial loads) in kWh; p_{inj} is the unitary price in € paid to the PV owner per kWh injected into the grid; E_{s_cons} is the amount of PV energy production self-consumed by the PV system's owner (different according to residential, commercial and industrial loads) in kWh; s_{bill} is the cost in €/kWh saved from the utility bill;
- the yearly Operation and Maintenance (O&M) cost C_{OM} in €/y;
- the real interest rate i^*.

According to the following formula, the real interest rate i^* takes into account the effect of the inflation rate f that reduces the basic interest rate i, if the feed-in tariff is updated through the inflation rate

$$i^* = \frac{i-f}{1+f} \cong i-f \quad \text{when } f \ll 1 \tag{2}$$

In fact, the present value of a future cash flow CF_k (at k-th year) that includes inflation rate is equivalent to a present value weighted by i^*, according to:

$$\frac{CF_k \cdot (1+f)^k}{(1+i)^k} \approx \frac{CF_k}{(1+i^*)^k} \tag{3}$$

The cash flows at k-th year is composed of multiple items in terms of both revenues and costs, characterized by different real interest rates: the situation is different between Germany and Italy. In particular, in Germany the real interest rates are two: one for the feed-in tariff, $i^*_{feed} = i$, not updated [34,14] according to the national inflation rate (determined by multiple goods and services), f, the other for the O&M costs, i^*_{OM}, that includes the national inflation rate [29], calculated as a mean value in the last ten years according to Eq. (2):

$$i^*_{OM} = i - f \tag{4}$$

On the other hand, in Italy the real interest rates are three: the first two items are the same (feed-in tariff not updated according to the inflation [34]), the additional item, that deals with the on-site-exchange, i^*_{ose}, is defined by the national inflation rate of the electricity as a single good, f_{elec}, ([6]. Electricity market), ([7]. Energy Prices), ([8]. Electricity prices, domestic consumers), ([9]. Electricity prices, industrial consumers), according to Eq. (2):

$$i^*_{ose} = i - f_{elec} \tag{5}$$

Many papers present suitable formulas for the economic analysis of investment in renewable energy installations [35,10,11,40]. Here the discussion starts from Eq. (1), in order to define basically *NPV* as a mathematical series after *N* years of operation. In our case, the *NPV* after 25 years of guaranteed energy production (20 years of feed-in tariff in Germany and Italy and 25 years of on-site exchange in Italy), is defined as

$$NPV = -C_I + \sum_{k=1}^{N} \left[\frac{(E_{AC} \cdot p_{PV})}{(1+i)^k} + \frac{(E_{g\_inj} \cdot p_{inj} + E_{s\_cons} \cdot s_{bill})}{(1+i^*_{ose})^k} - \frac{C_{OM,k}}{(1+i^*_{OM})^k} \right] \tag{6}$$

As previously mentioned, it is possible to evaluate the investment through economic indicators, such as the net present value and the internal rate of return.

- *NPV* of a time series of cash flows is defined as the sum of the present values of the individual cash flows of the same entity. The interest rate takes into account the alternative uses of capital, or the minimum return that an investment must generate in order to equalize an investment of equal duration and risk on the financial market. Therefore, *NPV* takes into account the lacking revenues arising from the alternative use of money. If an investment is associated with a positive *NPV*, it is

not only convenient from the economic and financial point of view but can be also more convenient than other investments with similar characteristics. A negative *NPV* means the investment return is less than the alternative one.

- The interest rate of the cash flows of an investment is equal to the Weighted Average Cost of Capital (WACC). WACC is calculated considering only objective parameters, such as the rate of return without risk (long-term government bonds, e.g. German "bund"), or the Market Premium between the return of a portfolio of stock titles and the return rate without risk.
- *IRR* is a financial viability indicator and represents the yield of an investment. *IRR* is an annual compound rate of the real return of investment. In general, an investment should be pursued when *IRR* is greater than the Minimum Attractive Rate of Return (MARR), which coincides with the normal rate of return for an investor or a company. Mathematically, *IRR* is defined as the interest rate that makes the *NPV* of a series of cash flows equal to zero. According to this criterion, an investment is desirable when *IRR* is greater than another reference rate (for example, WACC).

Based on these considerations, a possible analysis of economic investment for PV systems on rooftop in Italy and Germany is made, considering both the various rules of feed-in tariffs and the current installation costs. Obviously, this analysis should take into account the geographical location of the PV system or the predicted productivity.

Actually, in the economic analysis of a grid-connected PV system, it is necessary to calculate, with adequate accuracy, the yearly electricity production at the AC terminals (E_{AC}). Therefore, the following formula can be used [30]:

$$E_{AC} = P_{PVm} \cdot N_m \cdot Y_r \cdot PR \tag{7}$$

where: $P_{PVm} \cdot N_m$ is the total rated power of the PV array P_{PVr}, constituted by N_m equal modules with individual rated or peak power (i.e., in the maximum power point) P_{PVm} at the Standard Test Conditions (*STC*, irradiance G_{STC}=1 kW/m^2, cell temperature T_{STC}=25 °C), declared by the manufacturer; Y_r is the reference yield, i.e. the ratio $H_g(\beta,\gamma)/G_{STC}$, in other words the ideal number of equivalent hours per year (peak solar hours); it is worth noting that the global irradiation $H_g(\beta,\gamma)$ is strongly dependent on the site with variations around the average value of $\pm$20% in Italy and $\pm$10% in Germany, in kWh/m^2, corresponding to the optimal tilt angle β with azimuth angle γ=0° (South orientation); *PR* is the Performance Ratio, i.e., the recommended parameter for comparing the PV systems. In case of building integration, *PR* is 2–5% lower (with crystalline silicon) for higher thermal loading consequent to less air circulation. Usual values are in the range 0.65–0.85 pu.

Finally, the yearly energy production of a PV plant characterized by P_{PVr} can be written:

$$E_{AC} = P_{PVr} \cdot Y_f \tag{8}$$

in which the final yield is Y_f=$Y_r \cdot PR$, i.e. the ratio of the energy production to the installed PV power (in kWh/kW$_p$).

Therefore, it is possible to calculate the revenues from electricity according to the productivity of the PV system and the feed-in tariff p_{PV} by the German and Italian formulas, respectively:

$$R_{PV} = P_{PVr} \cdot Y_f \cdot p_{PV} \text{ and } R_{PV} = P_{PVr} \cdot Y_f \cdot p_{PV} + P_{PVr} \cdot Y_f \cdot p_{inj} \cdot \alpha_S + P_{PVr} \cdot Y_f \cdot s_{bill} \cdot (1-\alpha_S) \tag{9}$$

where, as a first approximation, the share of energy sold to the grid α_S=0.7 for loads $<$=20 kW$_p$ and α_S=0.3 for loads $>$20 kW$_p$, whereas the remainder $(1-\alpha_S)$ is the saved energy. In the Italian formula the price paid to the PV owner per kWh injected into the grid p_{inj} is curtailed through a taxation [31], that is typically assumed equal to 20% [41].

Due to purposes of comparison between PV systems of different size, the *NPV* equation can be divided by the rated power P_{PVr} to obtain *npv* in €/kW$_p$. If we introduce the Capital Recovery Factor (CRF, defined in [10]), each term of the summation, except the installation cost, is divided by its CRF:

$$\begin{aligned} npv = NPV/P_{PVr} &= -c_I + (p_{PV} \cdot Y_f) \cdot (1-(1+i)^{-N}/i) \\ &+ (p_{inj} \cdot Y_f \cdot \alpha_S + s_{bill} \cdot Y_f \cdot (1-\alpha_S)) \\ &\cdot (1-(1+i^*_{ose})^{-N}/i^*_{ose}) - c_{OM} \cdot (1-(1+i^*_{OM})^{-N}/i^*_{OM}) \end{aligned} \tag{10}$$

where $c_I = C_I/P_{PVr}$ is the specific installation cost in €/kW$_p$; $c_{OM} = c_I \cdot C_{OM}/C_I$ is the O&M cost expressed as a percentage of the specific installation cost.

In conclusion, the ratio of the *npv* to the specific installation cost permits the definition of a normalized index of profitability npv_{pu} in per unit, as displayed in the following case studies.

4.2. Case studies in Italy and Germany

Generally speaking, the production of goods or services follows the experience curve (or learning curve). Each time cumulative volume doubles, value added costs (including manufacturing, marketing, distribution, etc.) fall by a constant percentage [12,18]. With reference to the cumulative installation volume of grid-connected PV power in Italy and Germany (more than 50% of the world PV market), the experience curve of the global installation cost and the same curve of the main item, i.e., the PV module cost, are shown in Fig. 1 made by the authors on the basis of statistical data (IEA, 2011–2006, Trends in PV applications [23–28]). It is worth noting that every doubling in the market volume corresponds to about -19% reduction in the installation cost and about −25% reduction in the PV module cost. Thus, in long run (6 years) the percentage of the PV module cost decreases with respect to the installation cost from 75% down to 40%.

Now, it is possible to analyze each PV investment, referring to Central Italy and Central Germany: in this case the final yield per year from PVGIS website is roughly 1250 kWh/kW$_p$ for Italy and 875 kWh/kW$_p$ for Germany in 2006. Due to the continuous improvement in the design methodology, installation techniques, efficiency and availability of commercial inverters, it is supposed an increment of 1% per year in the yearly productivity.

About the possible PV investments in the economic analysis during seven years (since 2006 to 2012), four types of PV systems installed on rooftop for energy saving are considered, by assuming money paid by the owners and typical O&M costs [3,45]:

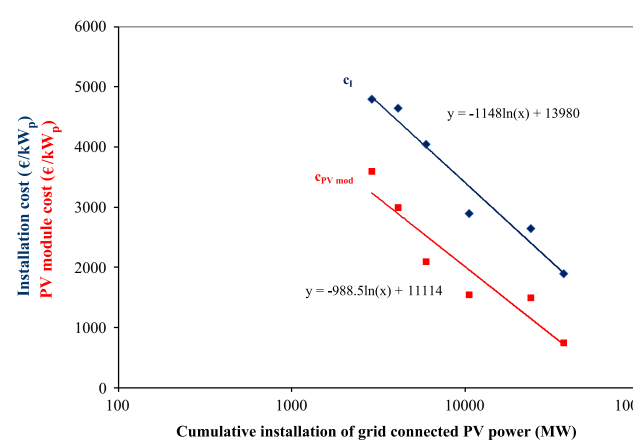

Fig. 1. Experience curves of installation cost and PV module cost vs. the installation volume of PV power (2006–2011).

1. *residential*, small size of 3 kW_p for Italy and 6 kW_p for Germany (due to major consumption typical at German latitudes with less sunlight hours), in which the investor is a family for satisfying the consumption of a dwelling house (O&M yearly cost = 1% of the total investment);
2. *commercial A*, size of 20 kW_p, typical for small business, in which the investor is a owner of a shop or a laboratory (O&M yearly cost = 1% of the total investment);
3. *commercial B*, size of 200 kW_p, typical for medium-large business, in which the investor is a company (O&M yearly cost = 1.5% of the total investment, higher than the previous cases due to the advisable periodic cleaning and monitoring);
4. *industrial*, size of 1 MW_p, typical for industrial business, in which the investor is a company (O&M yearly cost = 1.5% of the total investment, higher than the previous cases due to the advisable periodic cleaning and monitoring).

The incentive rates differ according to the current feed-in tariff (e.g. in Italy five different frameworks in the examined period) and the PV system size. The choice of the interest rate, derived from a financial investment with the same duration and risk of the PV installation in the considered Country, is influenced by the different investors (i = 4%, f = 2%, f_{elec} = 2.2%, for residential and commercial A investors, i = 7%, f = 2%, f_{elec} = 7.3%, for commercial B and industrial investors in Italy) and takes into account the different economic situation ([2], in which a 2%-spread is given in average) of Italy vs. Germany, where the interest rates are assumed 2% and 5%, respectively, whereas the inflation f = 1.7%.

The case-study results are shown in terms of time evolution of three quantities: the total specific installation cost c_I, the feed-in tariff p_{PV} according to the year and the *npv* in per unit or in percent with respect to the installation cost. The uncertainty bars in the *npv* index puts in evidence the difference due to the role of the site in the reference yield, according to the Northern Italy or Germany (lower) or to the Southern Italy or Germany (higher) installation. Moreover, in a single diagram the *IRR* trends are simultaneously displayed for all the case studies.

With reference to Italy, starting from the 1st phase of the CE, a forecasting analysis for 2013, with respect to the new feed-in tariff (i.e. the 5th CE) is represented. The forecasting analysis is examined in two limit conditions, defined when the self-consumed energy is 100% (best case, complete saving) and when zero self-consumption (worst case) occurs.

For the residential investor (Fig. 2), the *npv* performance follows the reduction of the installation cost and the feed-in tariff in the period 2006–2007, while it is constant (≈ 0.5 pu) in the period 2007–2008. From 2008 to 2010 a sharp increase occurs in the *npv* (up to 1.3 pu), due to the strong reduction of the installation cost and almost constant feed-in tariff (2nd CE from 2007 to 2010). The 3rd CE permits still a low increment in *npv* (1.5 pu), but, after this, the *npv* trend is declining down to 0.3–1.1 pu with the 4th–5th CEs, according to the share between the PV energy sold to the grid and the PV energy self-consumed.

In case of the 20 kW_p investor (Fig. 3) a sensible reduction of the *npv* trend is noted in the period 2006–2007 when the installation cost is almost constant. Then, in 2008–2010 interval the situation is similar to the previous case, even if the *npv* for 20 kW_p investor is quite higher (≈ 1.66 pu) than *npv* in the residential case. The major increase of the *npv* trend is in the period 2009–2010 when a noticeable reduction of the installation cost occurs. With the 3rd CE the trend of *npv* can no longer increase and the last two programs determine the decrements in 2012 and 2013 down to ≈ 0.47–1.49 pu.

Considering the 200 kW_p investor (Fig. 4), in the period 2006–2007 a low reduction of the *npv* trend is observed, due to an almost constant trend of the installation cost and a low reduction

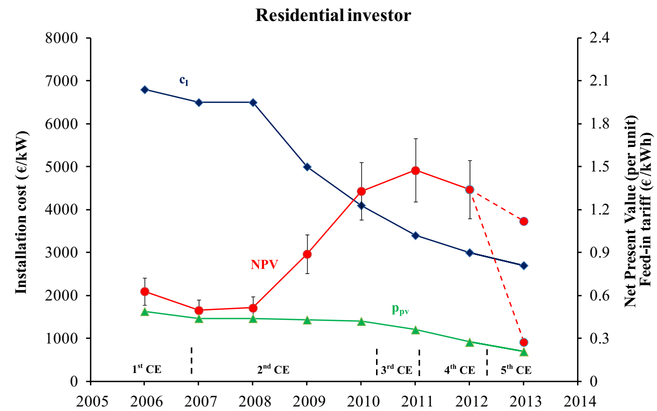

Fig. 2. The time evolution of the three quantities in the economic analysis for 3 kWp system in Italy.

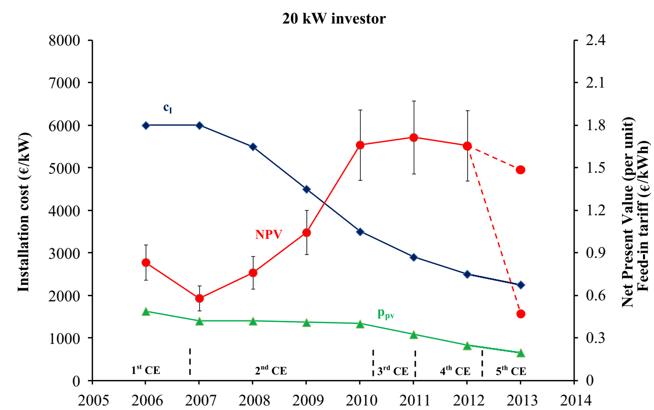

Fig. 3. The time evolution of the three quantities in the economic analysis for 20 kWp system in Italy.

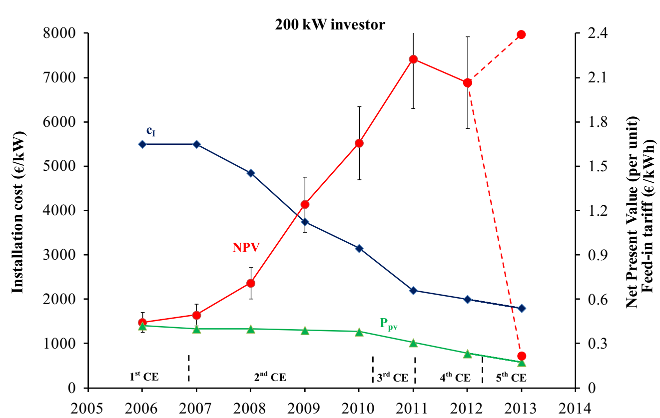

Fig. 4. The time evolution of the three quantities in the economic analysis for 200 kWp system in Italy.

in the feed-in tariff. Two increments of the *npv* trend are observed: the first in the period 2008–2009 and the second, which is the major, in the period 2010–2011 when a strong reduction of the installation cost occurs. The peak of *npv* happens with 3rd CE (≈ 2.2 pu) and then it deviates in the range 0.2–2.4 pu with 4th–5th CEs.

In regards to the industrial investor (Fig. 5), due to an almost constant trend of the installation cost in the period 2006–2007 but a low decrease of feed-in tariff, a low reduction of the *npv* trend is observed. Moreover, as the case of the 200 kW_p investor, two

increases of the *npv* trend are observed: the first in the period 2008–2009 which is the higher (from 0.7 to 1.5 pu) for a strong reduction of the installation cost, and the second in the period 2010–2011 (from 1.6 to 2.2 pu). In this case, with the 5th CE, the *npv* values drop to 0.1–1.5 pu, i.e., the minimum value for all the 4 investments.

It is noteworthy that, in all the examined PV investments, the period 2009–2010 has permitted the highest growth, whereas in 2011–2012 a change in the *NPV* trend occurs from positive to negative.

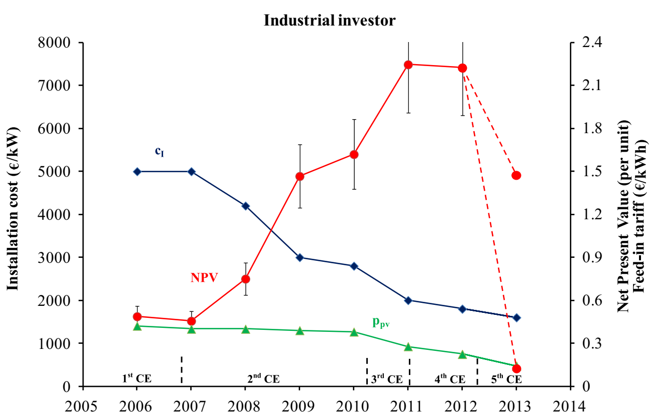

Fig. 5. The time evolution of the three quantities in the economic analysis for 1 MWp system in Italy.

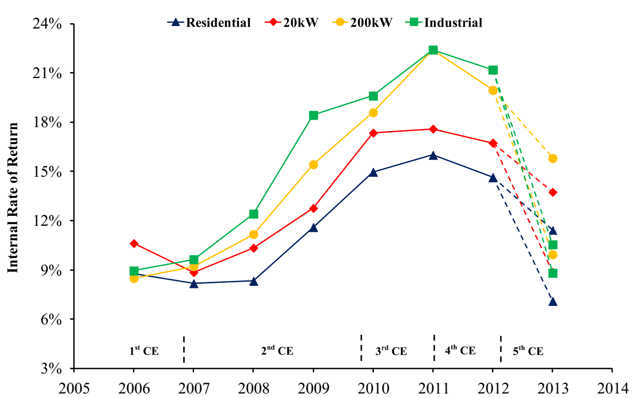

Fig. 6. The time evolution of IRR for all the four PV systems in Italy.

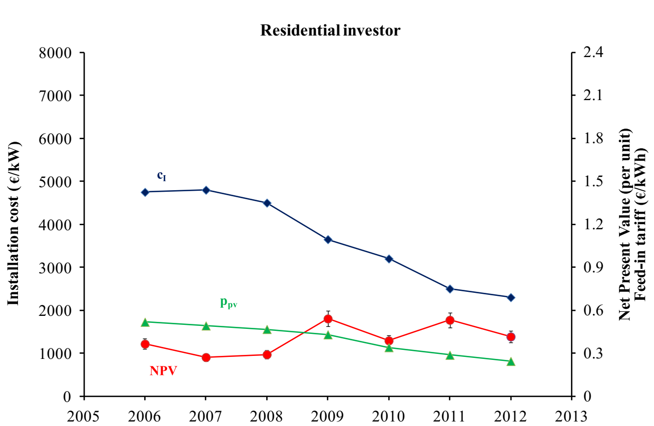

Fig. 7. The time evolution of the three quantities in the economic analysis for 3 kWp system in Germany.

Concerning the 2013 predictions about the residential and the commercial investors, the 5th CE permits still profitable *NPV* indices, if the self-consumption is maximized.

Fig. 6 shows the evolution of *IRR* index for all the investors: the two higher power sizes exhibit sensible gains in the interval 2009–2012, whereas in 2013 the values will go back to 2008 levels.

With reference to Germany, Figs. 7–10 show the economic indicators c_I, p_{PV} and *npv* in Germany. The evolution of *NPV* is similar couple by couple, i.e. the residential and 20 kW_p investors have always positive values, usually higher than 0.3 pu, while the

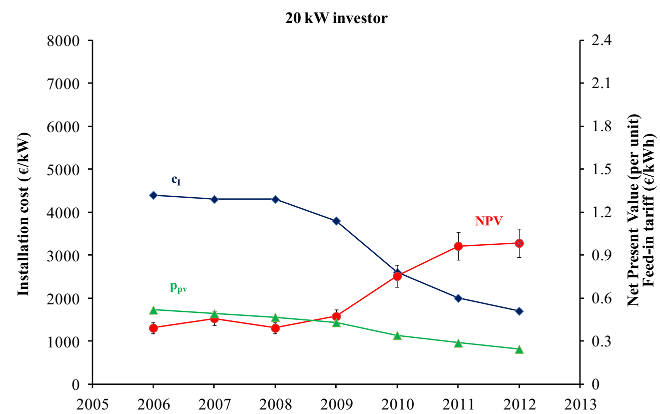

Fig. 8. The time evolution of the three quantities in the economic analysis for 20 kWp system in Germany.

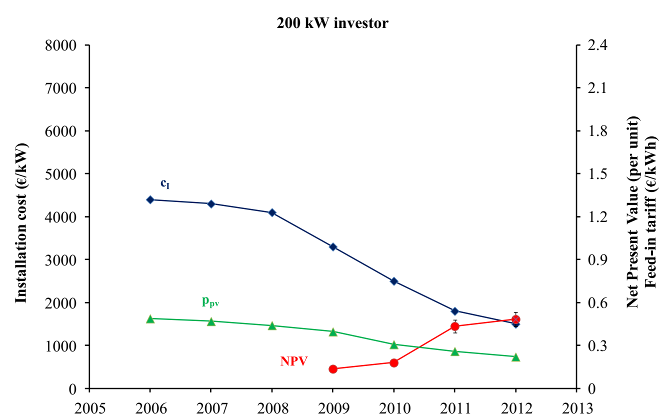

Fig. 9. The time evolution of the three quantities in the economic analysis for 200 kWp system in Germany.

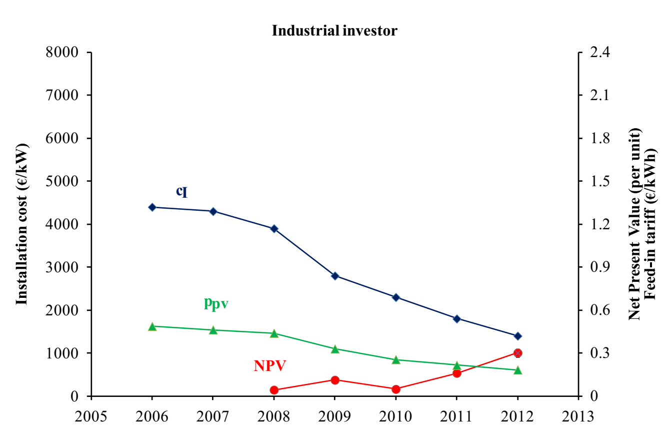

Fig. 10. The time evolution of the three quantities in the economic analysis for 1 MWp system in Germany.

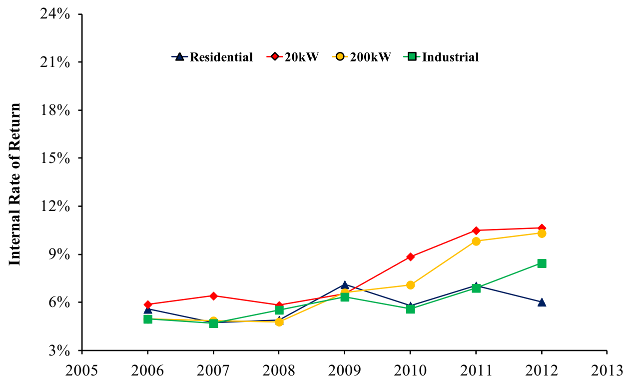

Fig. 11. The time evolution of IRR for all the four PV systems in Germany.

Table 5
Economic analysis results after 20 years of four Italian PV systems in 2012.

Type	*npv* (pu)	*IRR* (%)	*Z-NPV-P* Years
1	1.34	14.6	8
2	1.66	16.7	7
3	2.07	20.0	6
4	2.22	21.2	6

Table 6
Economic analysis results after 20 years of the four German PV systems in 2012.

Type	*npv* (pu)	*IRR* (%)	*Z-NPV-P* Years
1	0.42	6.0	13
2	0.98	10.6	9
3	0.48	10.3	11
4	0.3	8.4	13

200 kW_p and 1 MW_p investors exhibit $NPV > 0$ only since 2009 and 2008, respectively, with increasing trend in the last years. In particular, the 20 kW_p investment is the most profitable, the *npv* values are almost constant with a sensible increment in 2010–2012. Then, Fig. 11 shows the *IRR* graph, in which from 2006 to 2009 the indicators are superimposed for all the investors, whereas in the range 2010–2012 the medium size PV systems give the best economic gains.

Tables 5 and 6 show the economic-analysis results, after 25 years of each considered type (1–4), in which:

- *npv* (pu) is the *NPV* in per unit with respect to the initial cost of the investment;
- *Z-NPV-P* (Zero NPV Period) is the number of years when *NPV* without loan become zero.

The Italian market ensures till 2012 major profit margins: the *npv* indexes are always higher than 100% with peak up to 250% with the industrial investor; the *IRR* parameters are always higher than 10%. In Italian market the political incentive preserve large sizes of PV systems, in which the *npv* exceeds 200% and the Zero NPV Period goes down to 6 years, whereas in Germany the feed-in tariff pushes the development of medium size PV plants. This is due to the great Italian productivity and the incentive mechanism has not yet reached the same maturity as in Germany. Comparing Tables 5 and 6, for current year, there is a considerable convenience of PV market in Italy (with the 4th CE) for investors of the PV sector.

An economic analysis should take into account a possible funding body (i.e., a bank). The financial indicators to evaluate the investment should be compared in cases where the initial capital for the installation of the PV system belongs to the investor or it is anticipated by the lender, according to the current conditions of major Italian and German banking groups. Therefore, the financing terms vary depending on the PV plant size and private or company investors: a strong difference in the economic conditions between Germany and Italy occurs. The investment up to 100,000 € can be totally loaned with interest rate of 6–8% in Italy and 2–3% in Germany. On the other hand, above this threshold, the investment is partially loaned (70–80%) with interest rate around 10% in Italy and 4% in Germany with typical duration of 10–15 years ([32,39,42,43]).

If we analyzed the results, the financing of investment would involve interesting *NPV* achievements, for a zero initial capital (small plants) or minimum (20–30% of total). In particular, *IRR* without loan would be lower than the same with loan, corresponding to minimum risk. In fact, *IRR* is not appropriate to measure the actual convenience of an investment, because it does not consider the comparison among the investment cases in terms of *NPV*, but it considers only the percentage efficiency. Hence, a little investment with a very high *IRR* can have a lower *NPV* than a great investment with lower *IRR*. In other cases, when the investment does not provide negative cash flows, *IRR* cannot be calculated. Finally, if the own capital is invested, even if with a lower *IRR*, a *npv* higher than the unity without any risk is obtained. Thus, the cases with loan are not presented in this paper.

5. Concluding remarks

From statistical information in terms of learning curves the incentive policies bring to noticeable installation volume increments and cost decrements in the two main PV markets. The analysis presented in this article highlights the 2006–2012 profit margins of four different investments in rooftop PV systems, in which the 2012 economic situation is, by far, more profitable in Italy with $npv > 200\%$ of the installation cost after 20 years and $IRR > 20\%$ in the industrial PV system with respect to the best German PV system, characterized by $npv > 1$ pu and $IRR \approx 10\%$.

The maturity of German feed-in tariff is substantially reached in the last seven years, because the *NPV* and *IRR* parameters are subject to limited fluctuations, thanks to timely legislator regulations after the decline of the installation costs, whereas in Italy the situation in the studied period is affected by a stop-and-go mode. Here, the political intervention was so slow that the incentive rates had a little decay in 2007–2010, when the worldwide economies of scale in PV modules achieved an impressive decrement in the global costs and the national huge irradiation permitted booming production revenues. Consequently, the exaggerate profits, particularly in the PV systems belonging to the megawatt size, have almost saturated the global funds in the Italian electricity bill.

Concerning the near future, two joint reasons create concern in Italy: with the new feed-in tariff the 2013 economic indicators will drop close to the German levels, i.e., *npv* in the range 0.3–1.2 pu and *IRR* in the range 6–15%; then, the rapid penetration of distributed generation, as the PV systems, will require new grid-interface protections and new functionalities for the inverters in order to improve the network stability in case of unpredictable perturbations. Less problems are foreseen in Germany in these directions.

Finally, the long-term and sustainable development of PV systems, already in grid parity in Southern Italy, will be concentrated in the residential and commercial sizes, where the energy saving is substantial and the grid connection is already available and poorly influenced by the intrinsic variations of the PV power profiles.

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